Solar Concentrating Collectors
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PARABOLIC COLLECTOR FOR TOTAL ENERGY SYSTEMS APPLICATION

A. L. Levine, L. R. Paradis and K. L. Truesdale
Raytheon Company, Missile Systems Division
Bedford, Massachusetts

ABSTRACT

The Raytheon Company is participating in the ERDA/Sandia Laboratories total energy systems development program by designing and fabricating a parabolic, point concentrator solar collector.

The point concentrator designed and under construction is a toric parabola 6.7 m diameter, with an effective aperture of 35 m^2. Azimuth and elevation drive systems are computer controlled and provide maximum aperture utilization over the course of the year.

Mirrors are curved glass, hard mounted on an aluminum substructure, concentrating the solar energy into a cavity absorber located on the collector optical axis.

INTRODUCTION

Figure 1 is an artist's concept of the point concentration collector. The collector is a reflective toric parabola 6.7 m in diameter with an effective aperture of 35 m^2. The solar energy is brought to a ring focus at an annular entrance aperture of the cavity absorber located on the collector centerline.

The baseline parabolic design is based upon the size of the collector aperture and the magnification that is desired on the absorber surfaces. The absorber is cylindrical with a disc shaped upper section enclosed in a reflective canister. The absorber cavity has an annular input aperture of approximately 0.25 m^2. The absorber material is zirconium copper, plated with Harshaw black chrome selective coating. Absorber efficiencies of 90 percent are expected, attained by the relatively high energy concentration, the selective coating, minimization of reflected radiation leaving the absorber cavity, and the convection suppression effect of the cavity design.

The reflective parabolic design is implemented by spherical mirror segments hard mounted on an aluminum substructure. The mirrors are sagged, water white crystal glass, back silvered to provide maximum reflectance over the course of an expected twenty year life. Specular reflectance values on the order of 0.9 are expected from the mirrors.

The collector is driven in azimuth and elevation by dc stepping motors. The drives are computer controlled in an open loop incremental manner. The elevation drive system consists of a ball screw driven by a worm gear reducer from the stepping motor. A double reduction chain drive and worm gear comprise the azimuth drive system.

This work performed under Sandia Laboratories Purchase Order 02-7671B.

OPTICAL ANALYSIS

Figure 2 shows the main details of the collector design. The baseline paraboloid is a figure of revolution around the collector centerline. The optical axis of the generating parabola is not on the axis of rotation, resulting in a ring focus. The aperture to the absorber is at the collector focal plane.

The baseline paraboloid is approximated by many ($\approx$228) spherical mirrors. Design analyses were performed to optimize the size and orientation of the absorber surfaces and the size and radius of curvature of the spherical mirrors.

Figure 3 shows the results of the analysis of the magnification at the absorber surface. The absorber surface that was considered was a cylinder centered on the collector centerline, located past the collector focal plane. Figure 3 shows the magnification on the absorber surface versus distance from the collector focal plane for three absorber aperture radii and three absorber cylinder radii. The thermal design goals were an average magnification of 100 and a peak to average ratio of 3:1 over the absorber surface. Analyses have shown that the peak to average ratio and the magnification are relatively independant of the absorber cylinder radius; a 30 cm radius for the center of the absorber aperture was chosen.

Figure 4 shows the magnifications that are expected upon the absorber surface. The absorber design is a cylinder with a 18 cm radius and a 20 cm height. The cylinder is capped with a 30 cm radius disc. Input rays from the collector are incident upon the cylinder starting at 10 cm from the focal plane. Peak magnification for this design is about 350 and occurs on the cylinder close to the focal plane. Magnification on the cylinder varies from 100 to 350, while the magnification on the disc varies from 15 to 130. The average magnification on the irradiated area is 118.

ABSORBER

Figure 5 shows the mechanical design of the absorber and the absorber support assembly. The absorber support assembly is a post that bolts to the center of the collector assembly. Two fluid lines (one input, one output) come from a hose wrap assembly and go up the center of the support post to the top of the absorber. The insulating top of the absorber cannister is removable to allow the piping connection to be made to the absorber.

The absorber is bolted to the end of the support assembly. The absorber aperture annulas has a 30 cm radius and a 12.5 cm width. The absorbing surfaces of the cylinder and the disc are made from zirconium copper that is plated with Harshaw black chrome selective coating. The Therminol-66 fluid is sent through cupronickel tubing brazed to the back of the zirconium copper absorber surfaces. The nonabsorbing surfaces of the absorber assembly are made reflective. Insulation is used around the outside of the absorber to limit heat losses.

Figure 6 shows the results of thermal analyses on the absorber design. The input energy is .95 kW/m^2 times the aforementioned magnification factors and the fluid flow is 40 L/min. The Therminol-66 temperature increases 20°C from 293°C to 313°C with the assumed input and fluid flow rate. Maximum wall temperature of the cupronickel tubes is 370°C, while 381°C is the peak temperature of the zirconium copper absorber. Material compatability tests and tests on the selective coating indicate that the materials can handle the expected temperatures.

COLLECTOR DESIGN

The parabolic collector is approximated by 228 spherical mirrors in seven rings. This is shown in Figure 7. Mirror rings are constructed with a slight overlap to minimize mirror mechanical tolerance problems. The equation of the nominal parabola is

$$x = \frac{(y-a)^2}{4f}$$

where $a = 30$ cm
$f = 305$ cm

Because of the overlap configuration, each mirror can be considered to be on a slightly different parabola all with the same point as a focus. This family of parabolas can be represented by

$$x = \frac{(y-a)^2}{4(f-x_o)} + x_o$$

$$x_o = \frac{\Delta x}{1+\left(\frac{y-a}{2f}\right)^2}$$

where y = distance of the center of a mirror from the collector centerline
x = distance of the center of a mirror along the collector centerline
Δx = distance of the center of a mirror from the nominal parabola

The equation for the tilt of a mirror from the vertical is

$$\theta = \tan^{-1} \frac{(y-a)}{2(f-x_o)}$$

and the best radius of curvature for each ring is

$$R = 2(f-x_o)\left[1+\frac{(y-a)^2}{4(f-x_o)^2}\right]^{3/2}$$

Figure 8 shows the radius of curvature for the nominal and overlapped designs of a function of the distances from the collector centerline. The radii of curvature chosen are 6.35 m for the inner four rings and 7.5 m for the outer three rings.

A ray trace analysis was performed on the above optical design. The results for a point sun are shown in Figure 9. The third and sixth rings are almost perfectly focussed at the absorber aperture. The first, second and fifth rings focus past the absorber aperture, while the fourth and seventh rings focus before the aperture. The one-half degree sum dimension adds ±1.2 cm to the image made by the innermost mirror and ±2 cm to the image made by the outermost mirror. About 9 cm of the 13 cm absorber aperture will be used for the effects of radius of curvature errors and the angular size of the sun. The remaining 4 cm (±2 cm) allows for a ±6 mrad error for misalignment, pointing accuracy and mirror sagging errors. The present estimate of these errors is about 5 mrad.

PERFORMANCE PREDICTION

Figure 10 shows the performance that is estimated for the design that was described in this paper. The collector/absorber design is expected to meet the goals established by Sandia Laboratories.

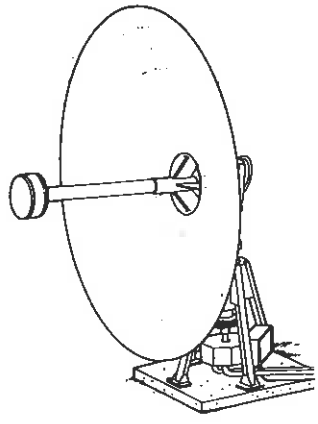


Figure 1 - Point Concentrator Collector

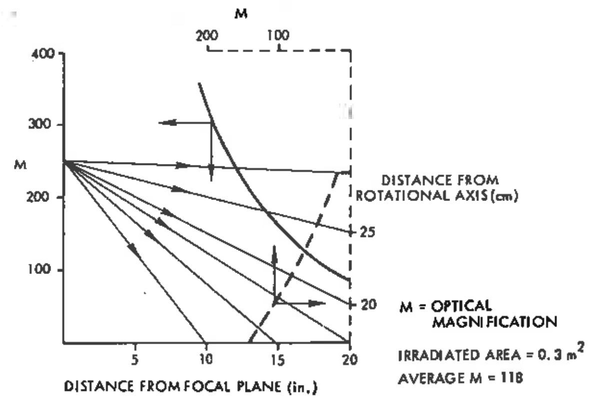


Figure 4 - Energy Distribution on Absorbing Surfaces

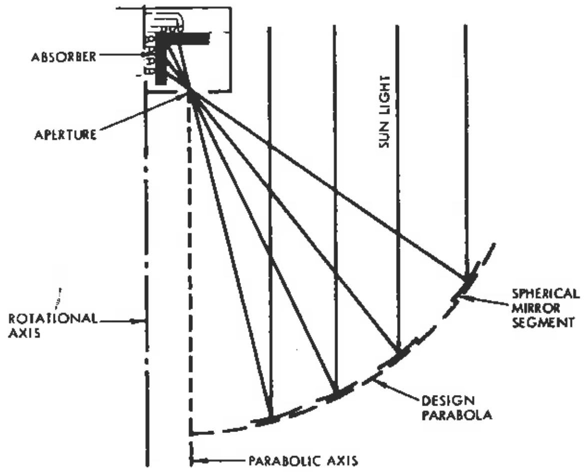


Figure 2 - Toric-Parabola Collector

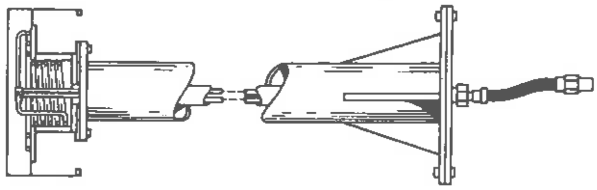


Figure 5 - Absorber Design

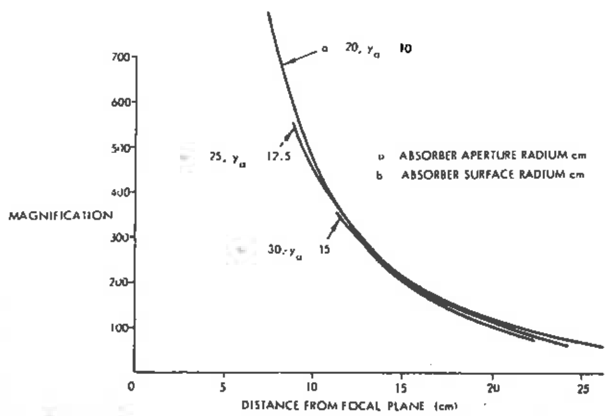


Figure 3 - Absorber Configuration Options

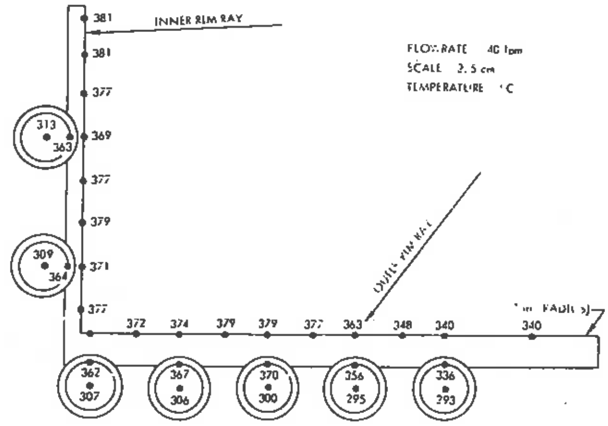
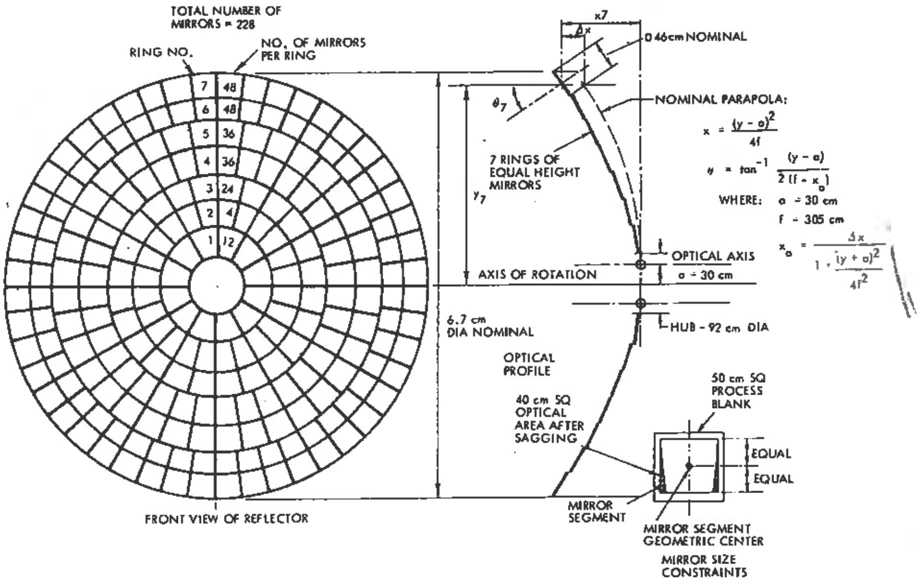


Figure 6 - Absorber Thermal Analysis



$$x = \frac{(y-a)^2}{4f}$$

$$\theta = \tan^{-1}\frac{(y-a)}{2(f-x_o)}$$

$$x_o = \frac{\Delta x}{1 + \frac{(y+a)^2}{4f^2}}$$

Figure 7 - Reflector Mirror Layout

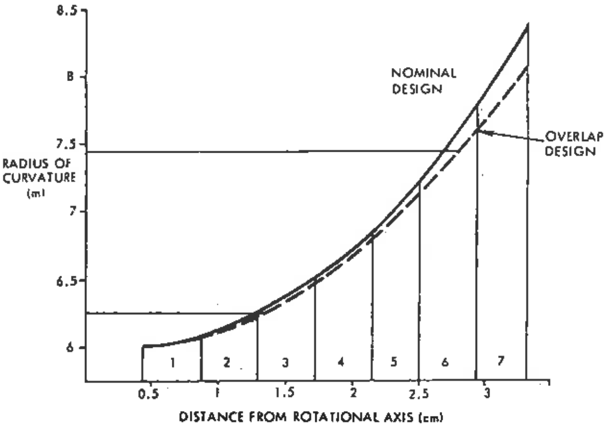


Figure 8 - Radius of Curvature for Design Parabola

	SUMMER SOLSTICE	FALL EQUINOX	WINTER SOLSTICE	SPRING EQUINOX
NET INCIDENT ENERGY (10^6 kJ/DAY)	1.32	1.17	0.99	1.18
MIRROR EFFICIENCY	0.92	0.92	0.92	0.92
ABSORBER EFFICIENCY	0.85 TO 0.94	0.85 TO 0.94	0.85 TO 0.94	0.85 TO 0.94
NET ABSORBED ENERGY (10^6 kJ/DAY)	1.03 TO 1.14	0.92 TO 1.01	0.78 TO 0.85	0.93 TO 1.02
MINIMUM NET ABSORBED GOAL (10^6 kJ/DAY)	1.06	0.97	0.8	0.95
COLLECTOR PIPING LOSSES (10^6 kJ/DAY) (AVG OF 11h/DAY	0.08 TO 0.12	0.08 TO 0.12	0.08 TO 0.12	0.08 TO 0.12
NET ENERGY DELIVERED (10^6 kJ/DAY) AT BASE OF COLLECTOR	0.92 TO 1.06	0.8 TO 0.93	0.66 TO 0.77	0.81 TO 0.94

Figure 10 - Prototype Collector Delivered Thermal Energy

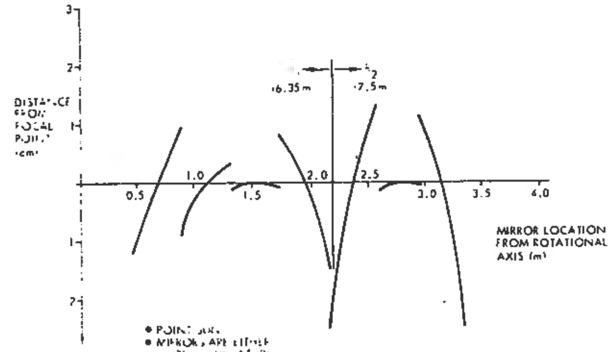


Figure 9 - Dispersion of Energy at Focal Plane